Critical Scales for Understanding Patch Dynamics and Impacts

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LONG -TERM GOALS

My long - term goal is to increase our understanding of the biological - biological, physical - biological and chemical - biological interactions that control the initiation, maintenance and dissipation of plankton patches. This goal can most readily be achieved by directly measuring processes thought to control plankton patch dynamics, experimentally testing their importance, incorporating those processes into conceptual plankton dynamics models, and then testing the models in the ocean.

OBJECTIVES

My short-term objective is to increase our understanding of the mechanisms controlling the dynamics and impacts of thin layers. Thin layers are patches of phytoplankton and zooplankton that range in thickness from 10 centimeters to a few meters, yet can extend horizontally for kilometers and persist for days. Recent work has shown that thin layers can be sufficiently intense and persistent to affect plankton dynamics and the performance of current and planned Navy optical and acoustical sensors. However, since much of this work has been done in the semi-enclosed waters of wind driven fjord, we have focused efforts this year on determining whether thin layers can have similar intensity and persistence in open coastal waters. At the same time, we have continued our efforts to develop our conceptual models of thin layer dynamics and impacts and publish the results of earlier studies.

APPROACH

Our approach during the past year has involved three closely related components. First, we have worked closely with WET Labs to insure that the autonomous profiler being developed under the ORCAS project (see report by Donaghay and Dekshenieks) would have the sensors and resolution needed to detect and characterize thin layers in open coastal waters. Second, we have collaborated with D.V. Holliday and M.A McManus in an effort to determine whether intensity, thickness and persistence of thin layers in open coastal waters is less than in the partly enclosed waters of East Sound. Our approach here was to use our newly developed ORCAS autonomous bottom-up profiler to collect a 1+ week time series of hourly finescale profiles of physical and optical structure in close proximity to a time series of acoustic measurements of zooplankton and current structure by Holliday. Third, we have worked very closely with D.V. Holliday, M. A. McManus and our other collaborators to insure the publication of the results of our work on thin layers in East Sound.

WORK COMPLETED

We have completed building and field testing of a version of our ORCAS mini-profiler that is capable of autonomously collecting centimeter-resolution profiles of optical, physical and chemical structure in open coastal waters. We have included spectral optical and bioluminescence sensors on this profiler to maximize our chances of detecting and characterizing the different types of thin particle layers that can occur in coastal waters. This required upgrading our existing WET Labs ac-9 spectral absorption and attenuation meters to the current state-of-the-art ac-9 plus with built-in DH4 data handler, building a version of the WET Labs VSF backscattering sensor that would match the 6 Hz rate of the ac-9, building intake extensions to sample thin layers before they could be disturbed by the profiler, and adding a bioluminescence sensor (provided by Drs. Alan Weidemann and James Case). We also completed versions of the data processing software that avoid averaging or interpolation techniques that can mask or modify finestructure.

We deployed one of our autonomous ORCAS mini-profilers at a 22 m deep site in the open waters of northeastern Monterey Bay in August 2002 and collected a time series of 178 hourly centimeter -resolution profiles of temperature, salinity, density, spectral absorption and attenuation (at 9 wavelengths), 150 degree backscatter at 532 nm, chlorophyll a fluoresence, bioluminesence, and oxygen concentration. The data from this system were radioed to shore, processed in near-real-time, and plotted so we could follow the development of any thin layers. We also used our ship-deployed profiler to collect high-resolution profiles in the waters around the bottom-up profiler so that we could verify the performance of the autonomous system, measure absorption by dissolved substances, and look at spatial variability in finescale structure. Following the cruise, we recalibrated the ac-9s, and reprocessed all the data. Plots of the finescale vertical physical and optical structure were made for each of the 178 profiles. These profiles were then used to identify thin layers, measure their peak intensity and thickness (@ 1/2 peak height), and the depth and density (sigma theta) at which they occurred. These layer characteristics were plotted versus time and compared to those seen in East Sound (and summarized by Dekshenieks, et al, 2001). We also used Spyglass Transform to plot the changes in vertical structure of each parameter over the 7+ days of the deployment and look at the relationships between physical and optical structure.

We have published 5 papers in the past year on our work on thin layers in East Sound. These include papers on the characteristics of thin layers in East Sound (Dekshenieks, et al, 2001), persistent thin layers of harmful algae (Rines et al, 2002); dynamics of marine snow layers (Alldredge, et al, 2002), the production of colored dissolved organic matter (CDOM) by thin algal layers (Twardowski and Donaghay, 2001), and the effect of photo-oxidation on CDOM layers (Twardowski and Donaghay, 2002). In addition, we have submitted 4 more papers including ones on advanced optical and acoustic techniques for sampling thin layers (Holliday, et al.), local and regional forcing of circulation in East Sound (McManus, et al., a), the effects of turbulence on dinoflagellate growth, mortality and distribution in East Sound (Sullivan et al., submitted), and a group paper on the 1998 thin layers experiment (McManus, et al., b).

RESULTS

Finescale optical structure measured by the autonomous profiler in Monterey Bay was remarkably similar to that measured previously in East Sound (Figure 1, 2). In both systems, centimeter scale sampling revealed the existence of thin (10 cm to 3 m thick at 1/2 peak height), intense (a440 values of up to 7 m^{-1}) layers that persisted for hours to days. As in East sound, these layers are too thin to be adequately resolved by conventional sampling techniques and thus have gone undetected despite extensive work in this system. For example, an intense (a440>1.5 m^{-1}) thin layer formed near the base of the pycnocline (Figure 1) and persisted for 5 days (Julian Day 220-225) (Figure 2) during which period it frequently shifted depth as internal waves moved the pycnocline up and down (Figure 3). This thin layer increased in intensity by orders of magnitude from initial low absorption coefficient values of 0.7 m^{-1} at 440 nm to extremely high values of 7 m^{-1} three days later, then declined back to initial values and a broad peak (Figure 2). It should be noted that this thin layer was as intense as any layer seen in East Sound. These results clearly demonstrate that thin layers can not only develop in open coastal systems such as Monterey Bay, but that they can become just as intense and persistent as they are in semi-enclosed waters of coastal fjords such as East Sound. As a result, they should have similar impacts on biological dynamics and sensor performance in open coastal waters. Given this, it is critical that we increase our understanding of the mechanisms controlling their dynamics so we can begin to predict their occurrence and impacts.

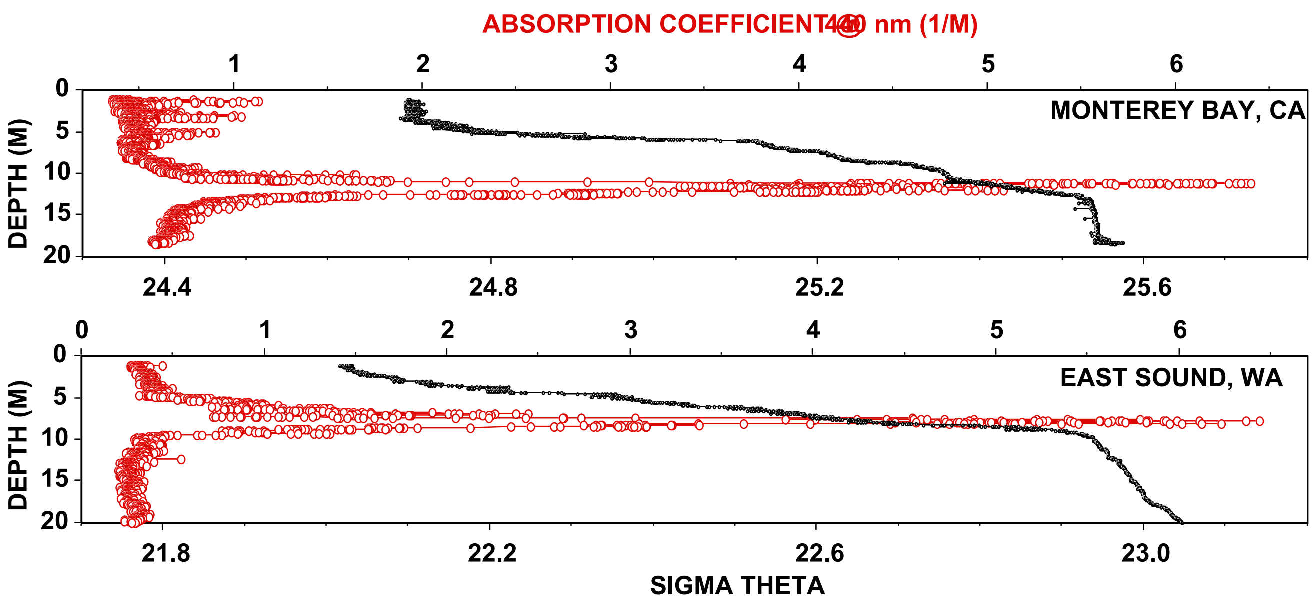

Figure 1. The figure shows that the finescale vertical physical and optical structure in northeastern Monterey Bay is remarkably similar to that in East Sound with the profiles of light absorption by particulate material (absorption coefficient at 440 nm - the peak wavelength of absorption by chlorophyll a) dominated by a thin (<1 m thick at 1/2 peak height), very intense (a440>6 m^{-1}) particle layer located near the base of the pycnocline. The pycnoclines are also quite similar with density differences of ~ 1 sigma theta spread over 10-15 m.

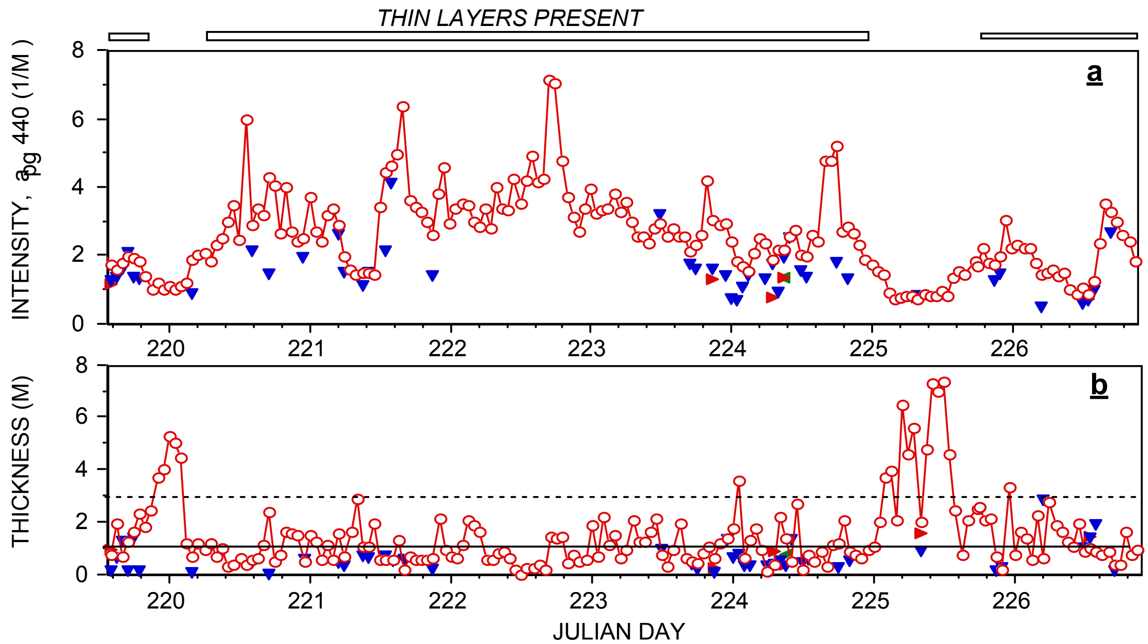

Figure 2. The figure shows that finescale optical structure in Monterey Bay oscillated between periods dominated by a low intensity (a440<0.7m-1), broad (>3m thick) absorption maximum and periods dominated by intense (a440 of 1-7 m^{-1}), thin (10 cm to 3m thick) layers that persisted for hours to days. Figure 2b shows that the range and modal thickness of these layers was similar to that seen in East Sound by Dekshenieks, et al, 2001 (represented by the dashed and solid lines in 2b).

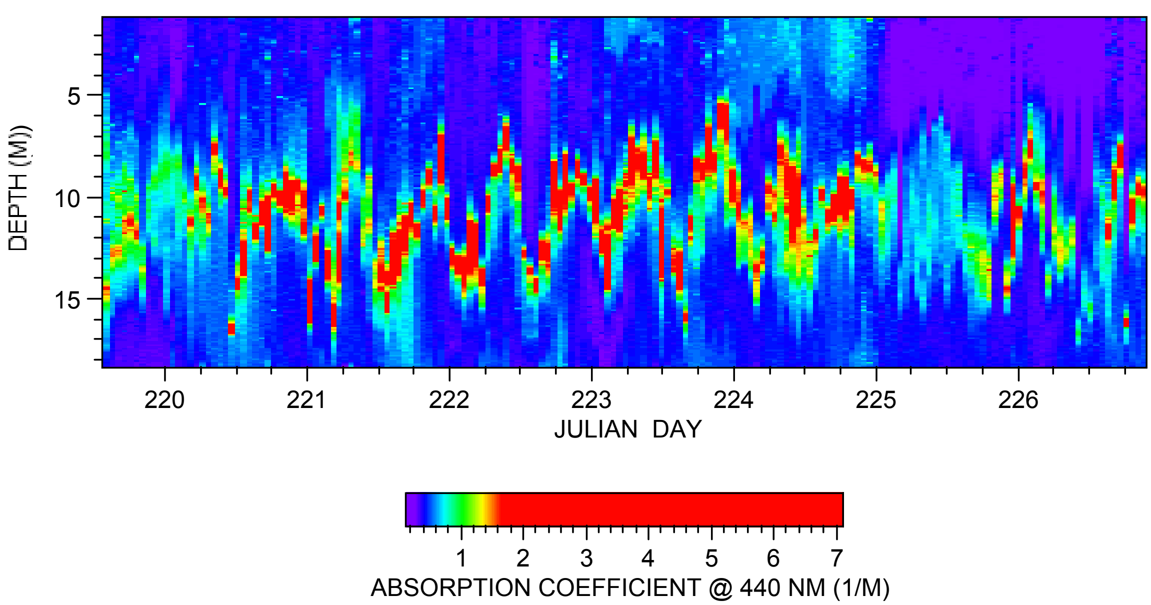

Figure 3. Temporal variability in the finescale vertical structure of the absorption coefficient at 440 nm during the week-long deployment in northern Monterey Bay. This figure shows that an intense (a440>1.5 m^{-1}) thin layer formed and persisted for 5 days (Julian Day 220-225) during which period it frequently shifted depth. These shifts in depth are highly correlated with changes in the depth of the pycnocline.

IMPACT/APPLICATIONS

One of the central assumptions in biological oceanography has been that small scale mixing processes in the upper ocean are sufficiently strong and equal in all directions that sub-meter scale biological, chemical and optical structures will be rapidly dispersed and thus can be ignored in both sampling and modeling upper ocean dynamics. Results from our joint studies with Holliday in East Sound and Monterey Bay clearly indicate that this assumption is frequently incorrect. Our field results and theoretical analyses indicate that biological-physical, biological-chemical and biological-biological interactions occurring at these scales may control not only the development of blooms of toxic and/or bioluminescent phytoplankton, but also the extent to which zooplankton are able to exploit phytoplankton production. Equally importantly, collaborative analysis of the data with experts in optics (Alan Weidemann, NRL-Stennis) and acoustics (D.V. Holliday, BAE Systems) indicates that finescale biological layers can be sufficiently intense to alter the performance of optical and acoustical sensors in coastal waters. These analyses also suggest that our bottom-up profiling systems have considerable potential for increasing our understanding biological dynamics and improving our interpretation of optical and acoustic data collected by other platforms.

TRANSITIONS

We have continued our efforts to transition our research to the Navy and private industry. First, we have developed a National Ocean Partnership Program project designed to extend and transition our 4-D finescale profiler technology. Partners in this project are Alfred Hanson (SubChem Systems), Casey Moore and Ron Zaneveld (WET Labs), Alan Weidemann (NRL-Stennis), LCDR Kimberly Davis-Lunde (Commander, Naval Meteorology and Oceanography Command) and Richard Green (Environmental Protection Agency Gulf Ecology Laboratory). Second, we have continued to work with Navy scientists and engineers at NUWC (Newport) to transition our results. Finally, we have worked very hard during the past year to make our work available to the research community by sharing data with our partners in the East Sound experiments and publishing joint papers.

RELATED PROJECTS

1. I am continuing a long-term collaboration with Van Holliday (BAE Systems) in trying to quantify zooplankton thin layers and understand how those layers are related to phytoplankton fine structure and physical forcing. We have shared data and spent several weeks working in his lab.

2. Margaret McManus (UCSC), Tom Osborn (Johns Hopkins) and I are trying to understand large scale physical forcing of thin layer dynamics.

3. Jan Rines (URI) and I are working on the role of small-scale mixing processes in controlling the dynamics of non-spheroid diatoms. We are also working on a literature review and website summarizing the evidence for thin layers in marine waters.

5. Alan Weidemann (NRL Stennis), James Case (UCSC), James Sullivan (URI) and I are using a micro-profiler equipped with one of Case's bathyphotometer to study temporal and spatial variability in bioluminescence and its association with finescale physical and optical structure.

PUBLICATIONS

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